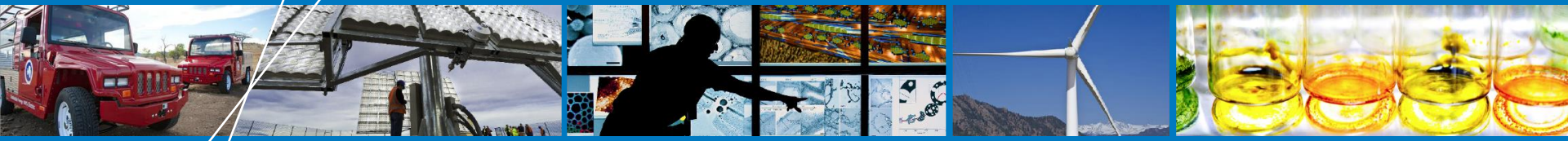
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Geothermal's Role in an "All of the Above" Energy Strategy

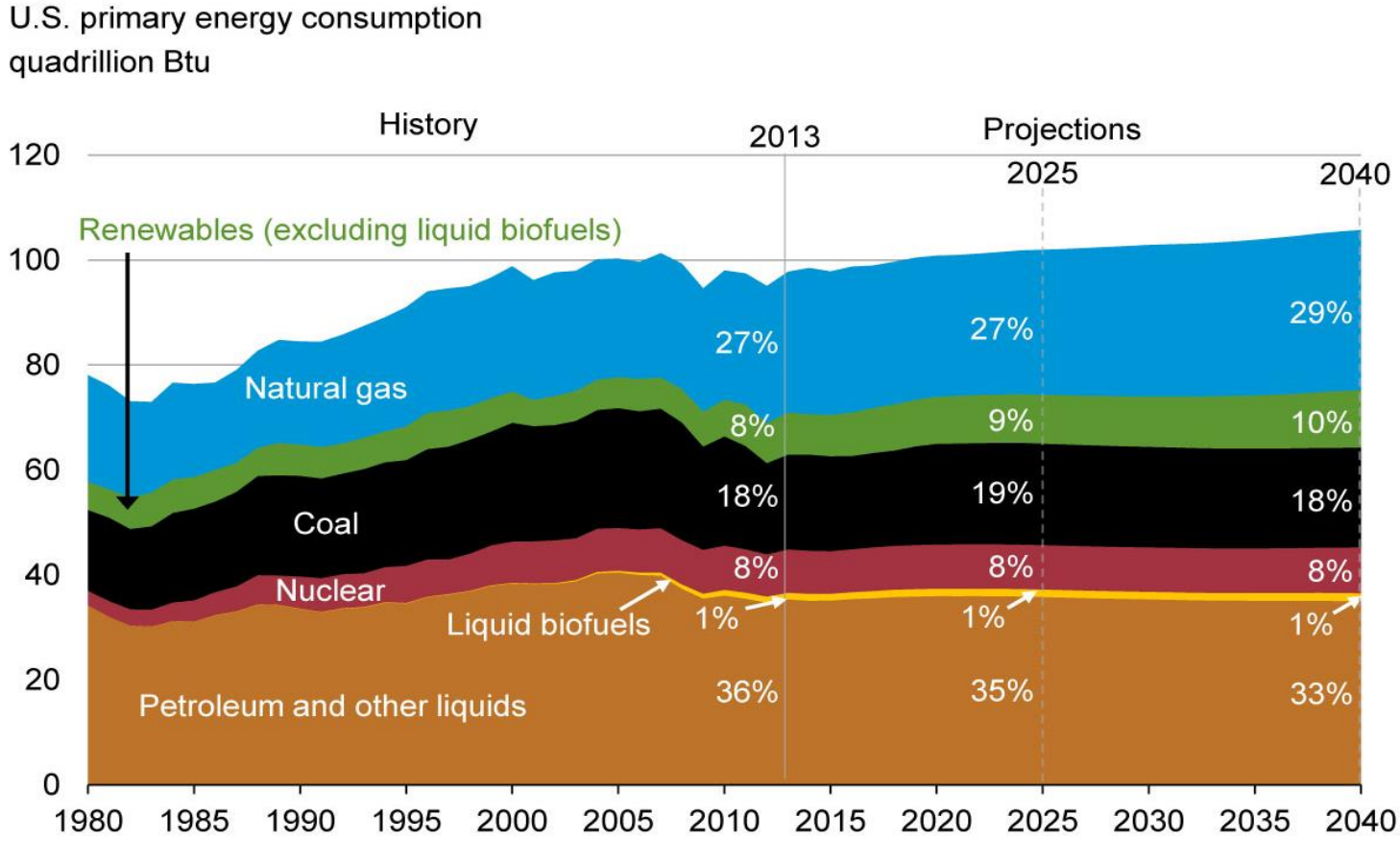


EERE GTO Program Review -- May 12, 2015

Dr. Michael A. Pacheco
Associate Laboratory Director, NREL

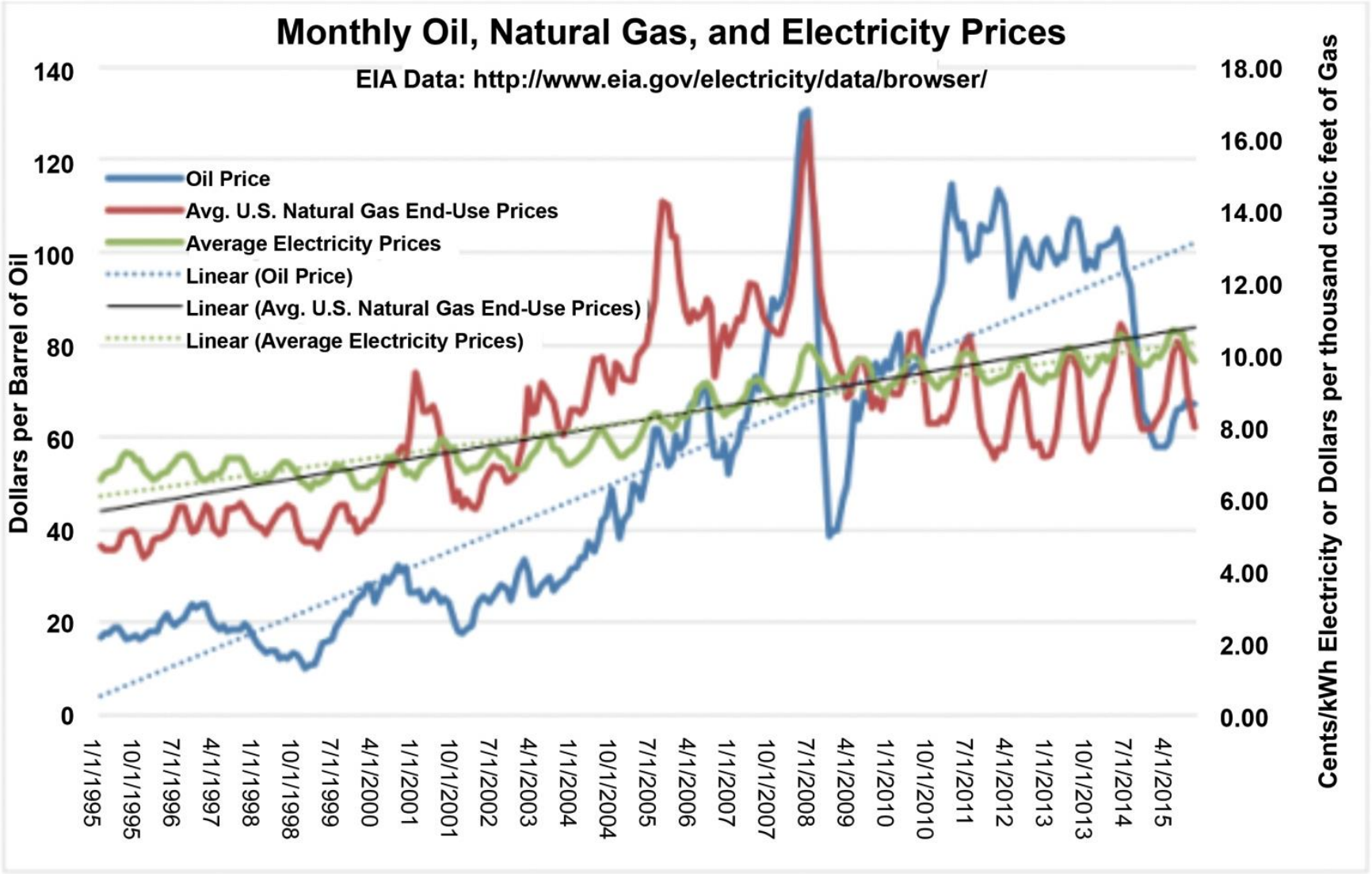
U.S. Energy Market: Large, Complex, & Slow-to-Change

Reductions in energy intensity largely offset impact of GDP growth, leading to slow projected growth in energy use



Source: EIA, Annual Energy Outlook 2015 Reference case

Energy Prices: Upward Trend and High Volatility



A Profound Transformation is Required

Today's Unsustainable Energy System

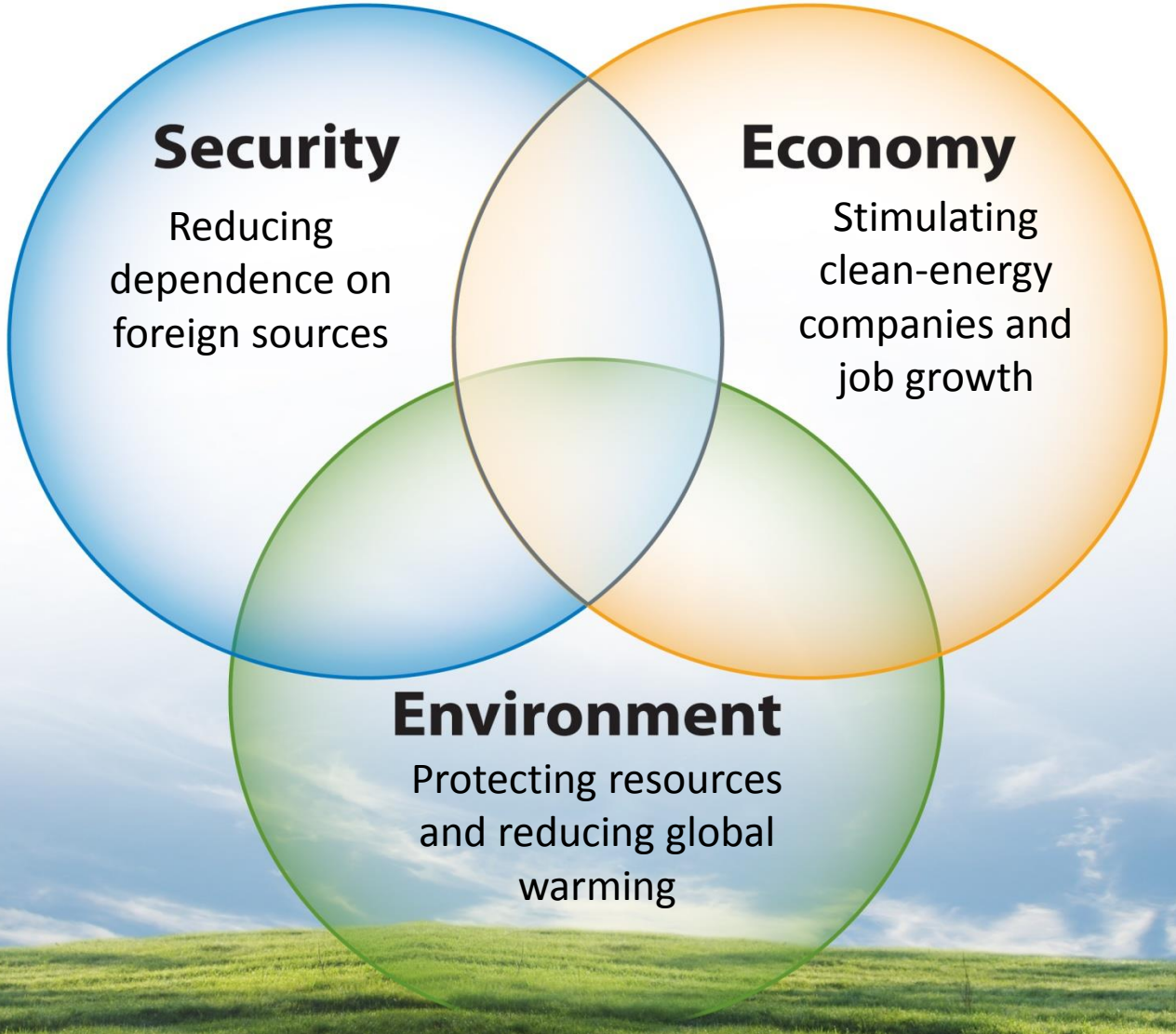
- Limited fuel diversity
- Subject to price volatility
- Inefficient and rigid
- Significant carbon emissions
- Delivery systems vulnerable
- Aging infrastructure

TRANSFORMATION

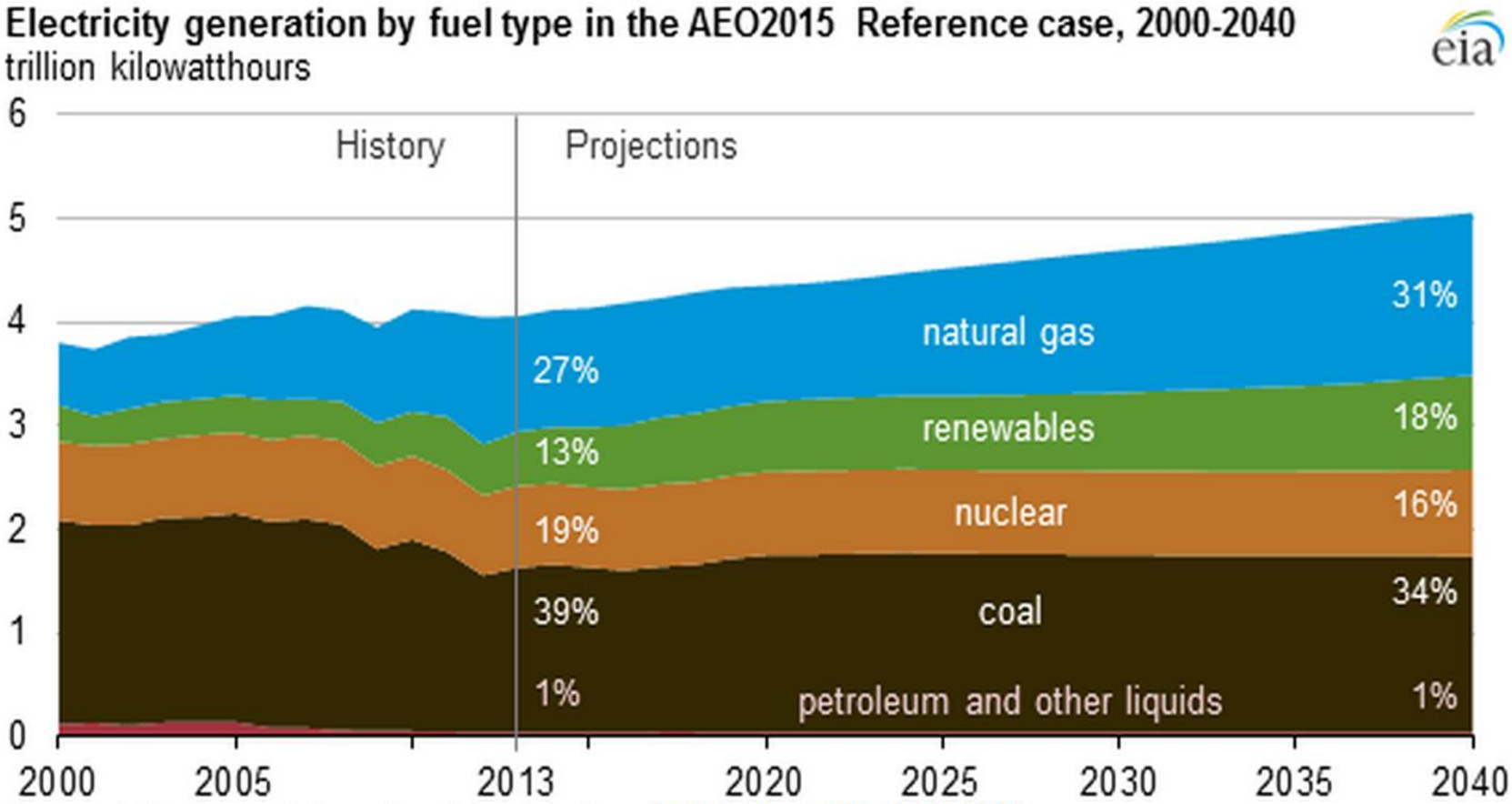
Future Sustainable Energy System

- Diverse supply options
- Affordable, stable and reliable
- Efficient and flexible
- Carbon neutral
- Secure and resilient
- Engine for innovation

The Transformation Must Address Three National Energy Imperatives

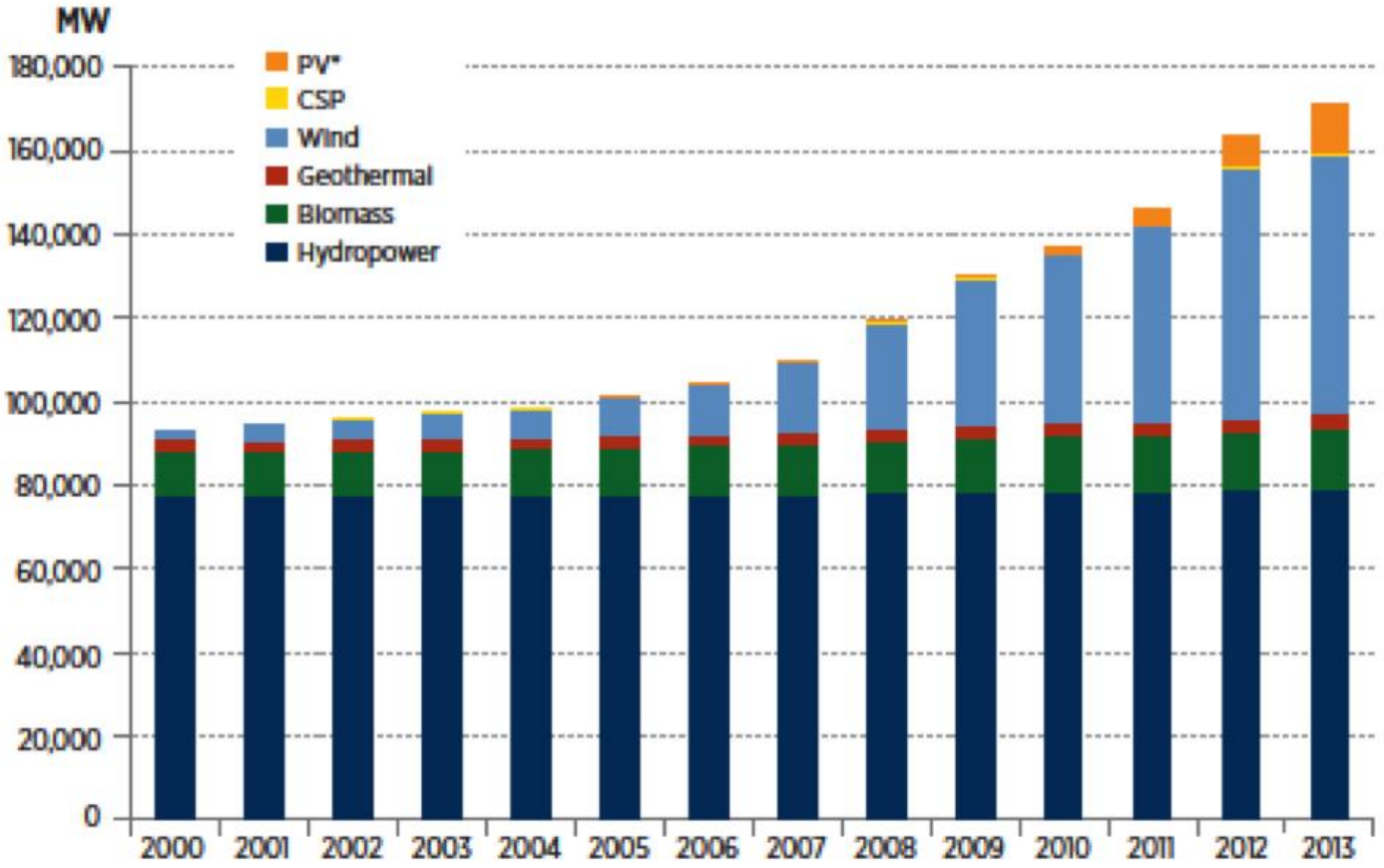


NG & RE Are Meeting Increased U.S. Electricity Demand



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2015*

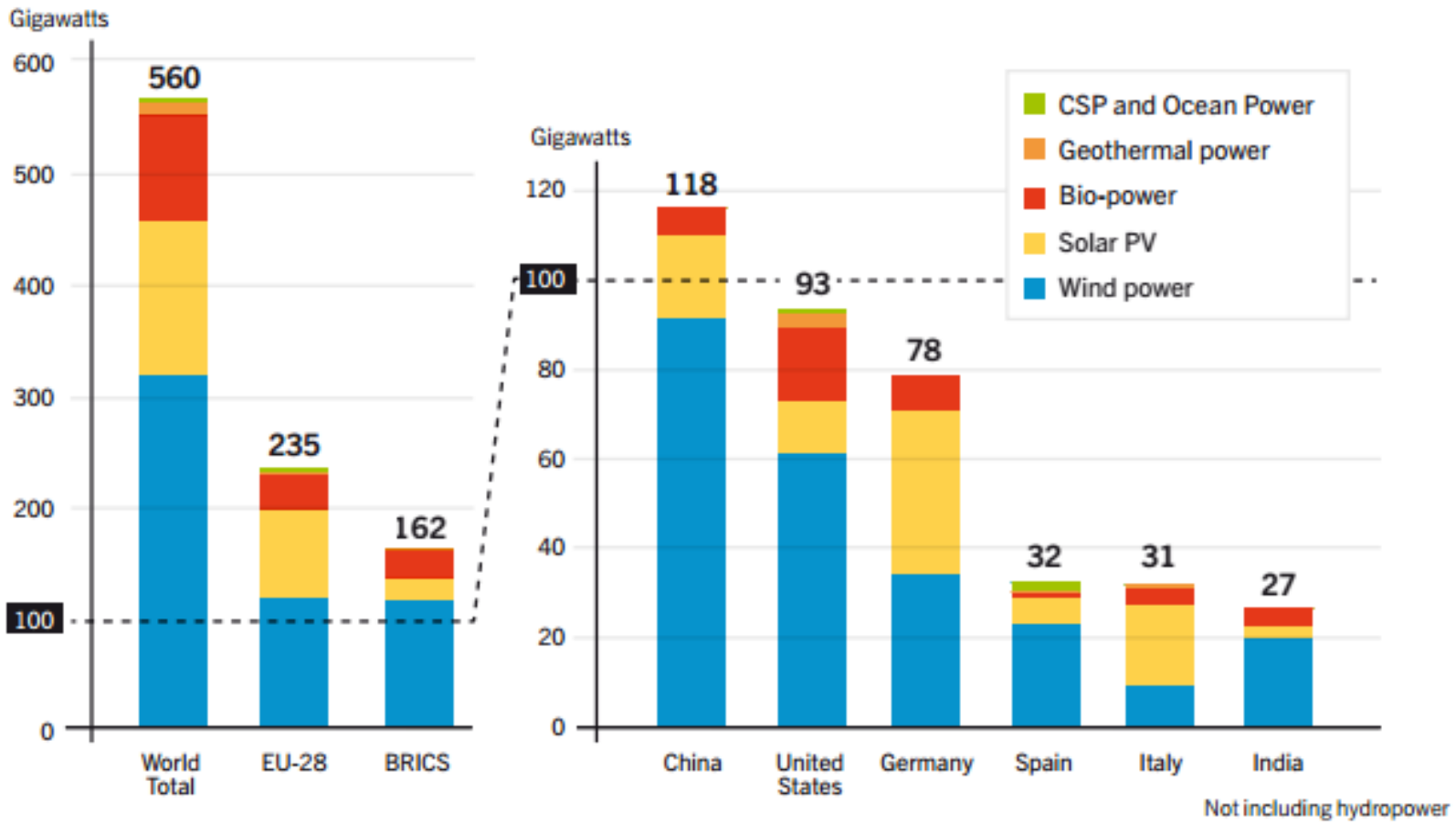
U.S. Renewable Power Capacity Growth by Source



Sources: EIA, GEA, LBNL, SEIA/GTM, Larry Sherwood/IREC
*Grid-connected only

2013 Worldwide Renewable Power Capacity

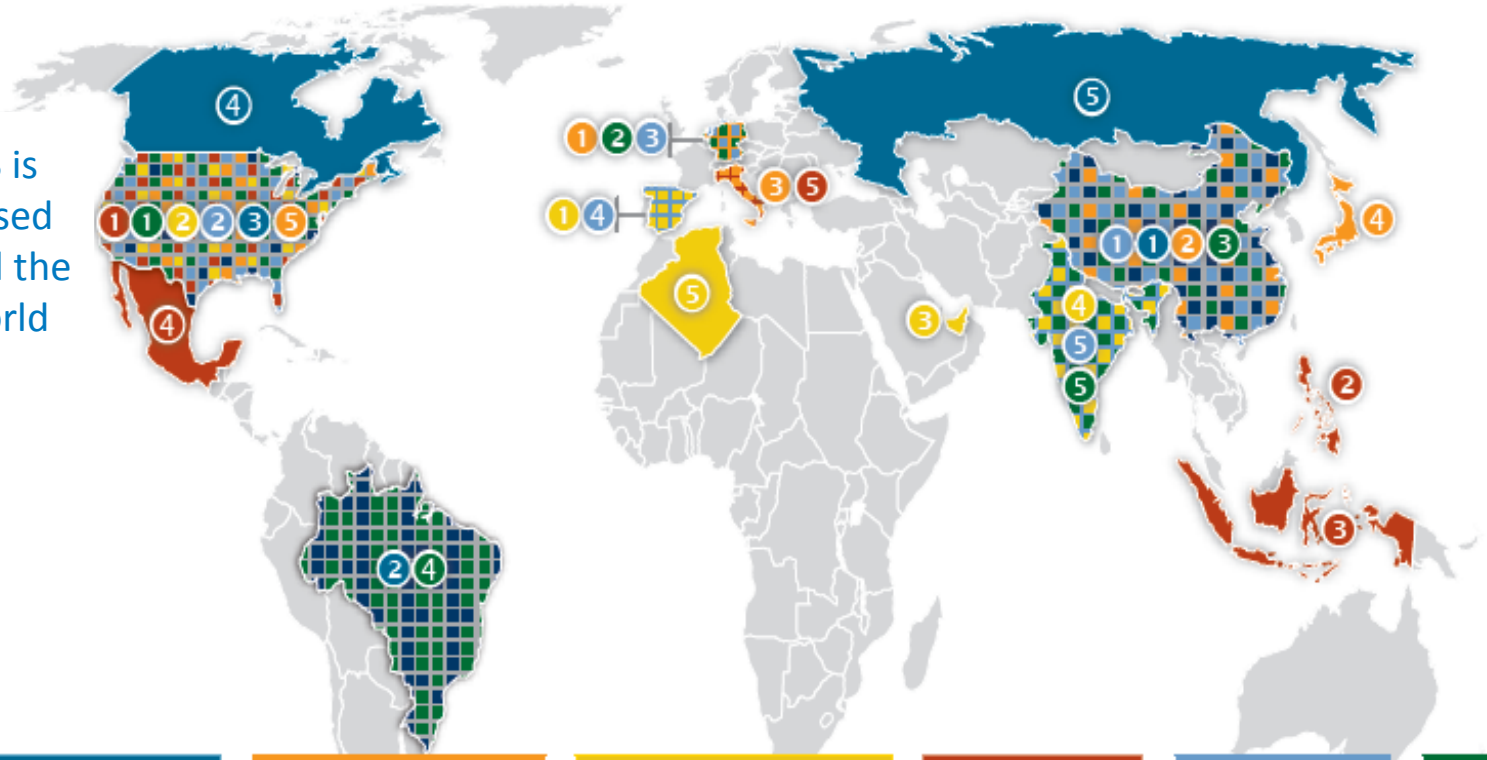
Figure 4. Renewable Power Capacities in World, EU-28, BRICS, and Top Six Countries, 2013



Source REN21 *Renewables 2014 Status Report*
http://www.ren21.net/Portals/0/documents/Resources/GSR/2014/GSR2014_full%20report_low%20res.pdf

Top Countries with Installed Renewable Electricity by Technology (2013)

US is Poised Lead the World



Hydropower	Solar PV*	CSP	Geothermal	Wind	Biomass
1 China	1 Germany	1 Spain	1 United States	1 China	1 United States
2 Brazil	2 China	2 United States	2 Philippines	2 United States	2 Germany
3 United States	3 Italy	3 United Arab Emirates	3 Indonesia	3 Germany	3 China
4 Canada	4 Japan	4 India	4 Mexico	4 Spain	4 Brazil
5 Russia	5 United States	5 Algeria	5 Italy	5 India	5 India

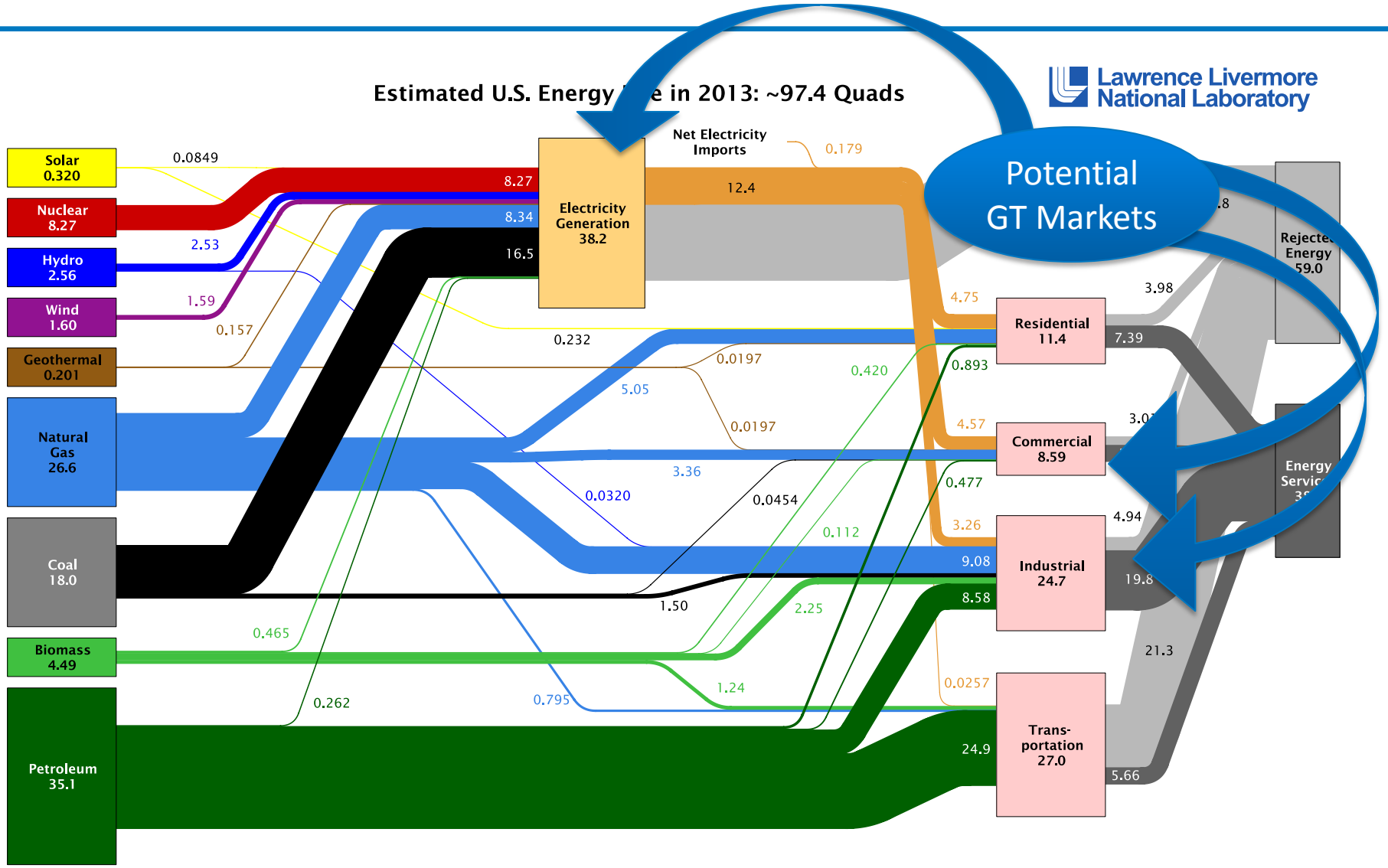
Sources: REN21

*Grid-connected only

50

Source: NREL 2013 Data Book

Geothermal Can Serve Several Energy Markets

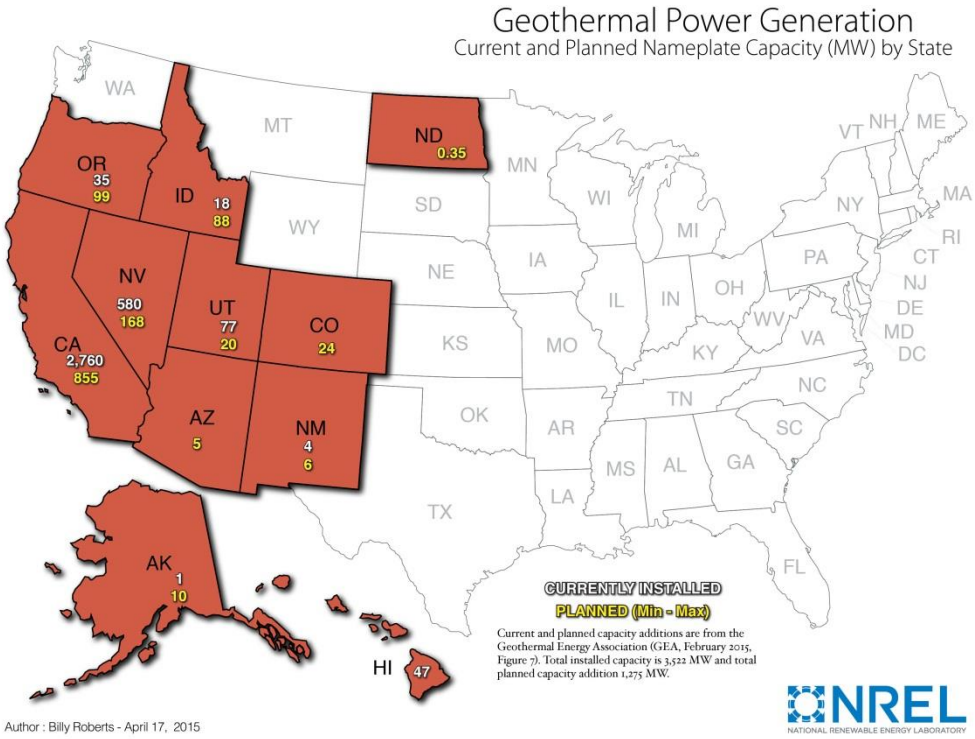


Source: LLNL 2014. Data is based on DOE/EIA-0035(2014-03), March, 2014. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports consumption of renewable resources (i.e., hydro, wind, geothermal and solar) for electricity in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential and commercial sectors 80% for the industrial sector, and 21% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

Geothermal Energy: *State of the Technology*

- PPA Prices: 8-11 cents/kWh
- Installed capital cost = $3,500-$5,500/kW.
- Binary geothermal power plants typically 10-30 MW in size.
- Flash and steam power plants typically 30-100 MW in size.
- Distributed generation options becoming available at 30 kW and above.
- Base load generation with high availability, and potential to operate as flexible generation.

Geothermal Power Deployed



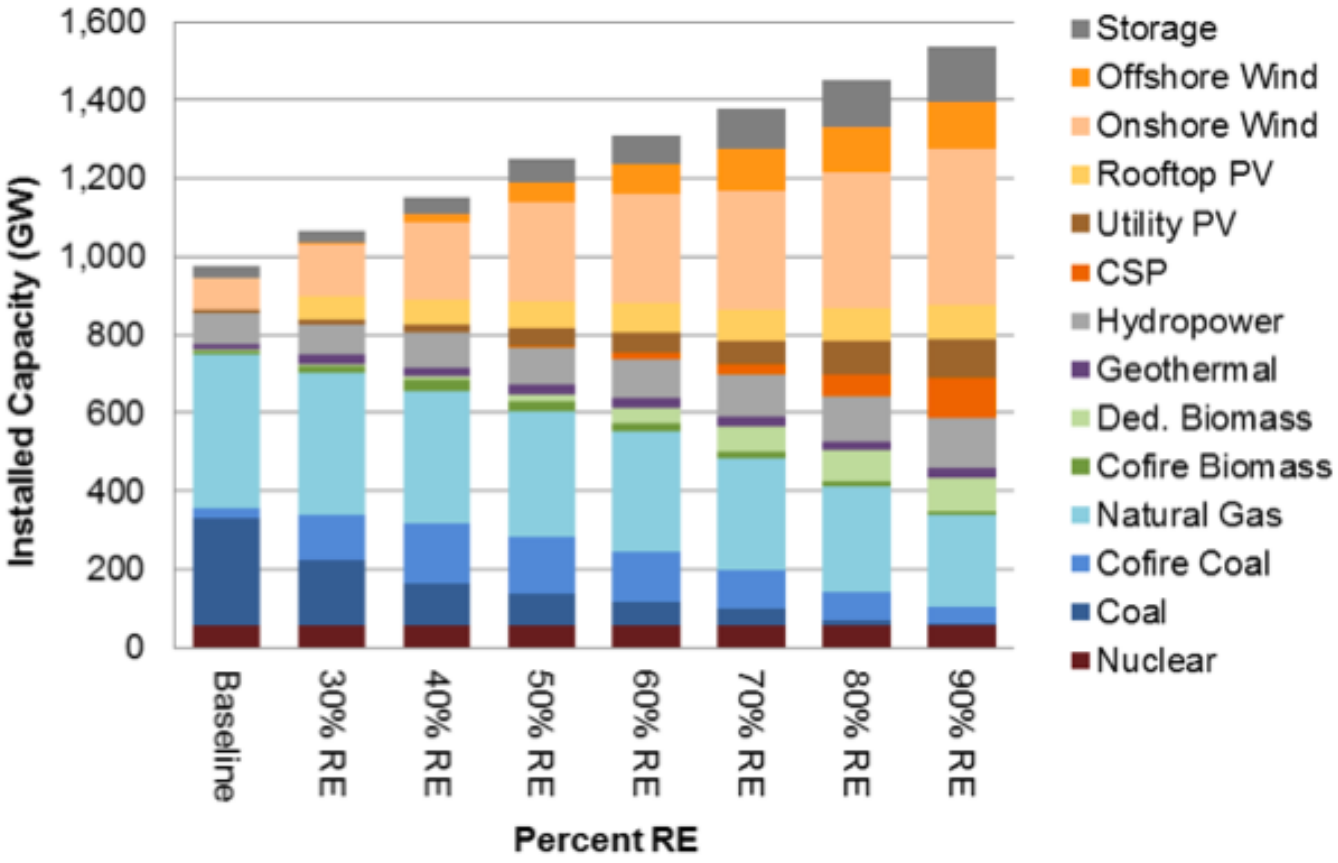
- Worldwide installed capacity: 12.8 GW (GEA, 2015).
- U.S. installed capacity: 3.5 GW (2/2015), the largest in world.
- U.S. has 1,250 MW of geothermal power under development
- 8 states with installed geothermal capacity, and 3 more states with projects under development.
- “Enhanced Geothermal Systems (EGS)” demonstration projects marking significant achievements, including first U.S. commercial, grid-connected EGS system.

Will Geothermal Remain a Minor Contributor?

Very high levels of renewable integration are technically achievable.

Results indicated high penetration for wind and solar in many scenarios.

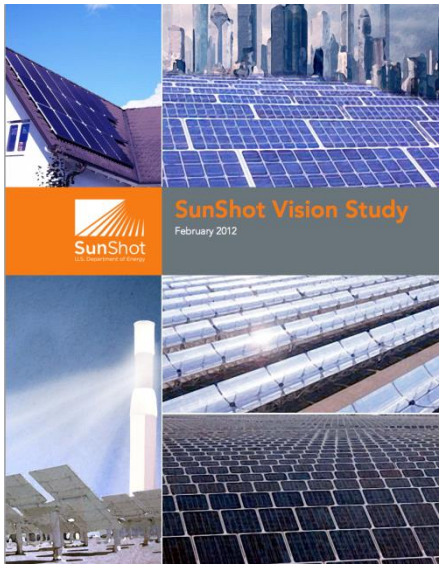
Geothermal remains a relatively minor contributor in future scenarios.

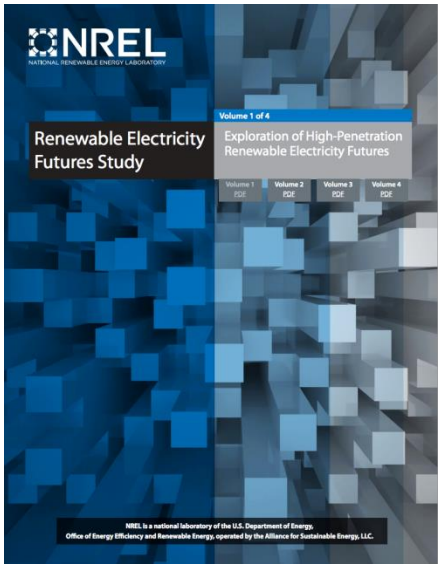


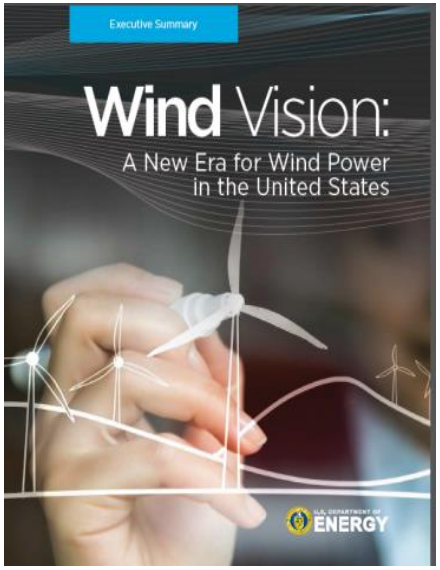
(a) Capacity mix in 2050 for the exploratory scenarios

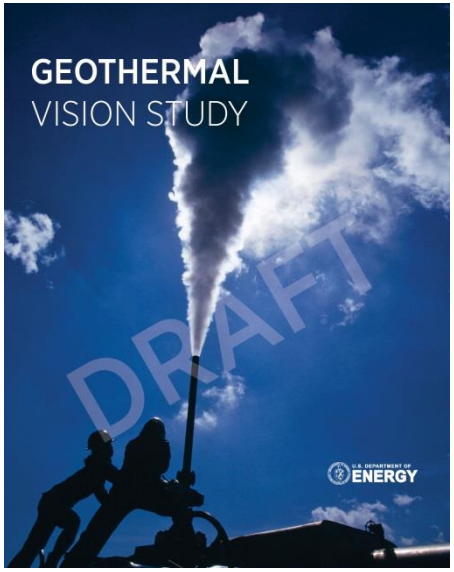
How can the Geothermal role be increased?

A Vision of High Penetration Geothermal









DOE has recently launched a geothermal specific vision study.

The new study present a vision of how to **Realize the Geothermal Potential …**

- Evaluate multiple geothermal growth scenarios for 2020, 2030, and 2050
- Inform and identify clear GTO investment strategies
- Address geothermal applications beyond electricity
- Technical contributors will include: NREL, ANL, INEL, LBNL, LLNL, PNNL, SNL, and USGS

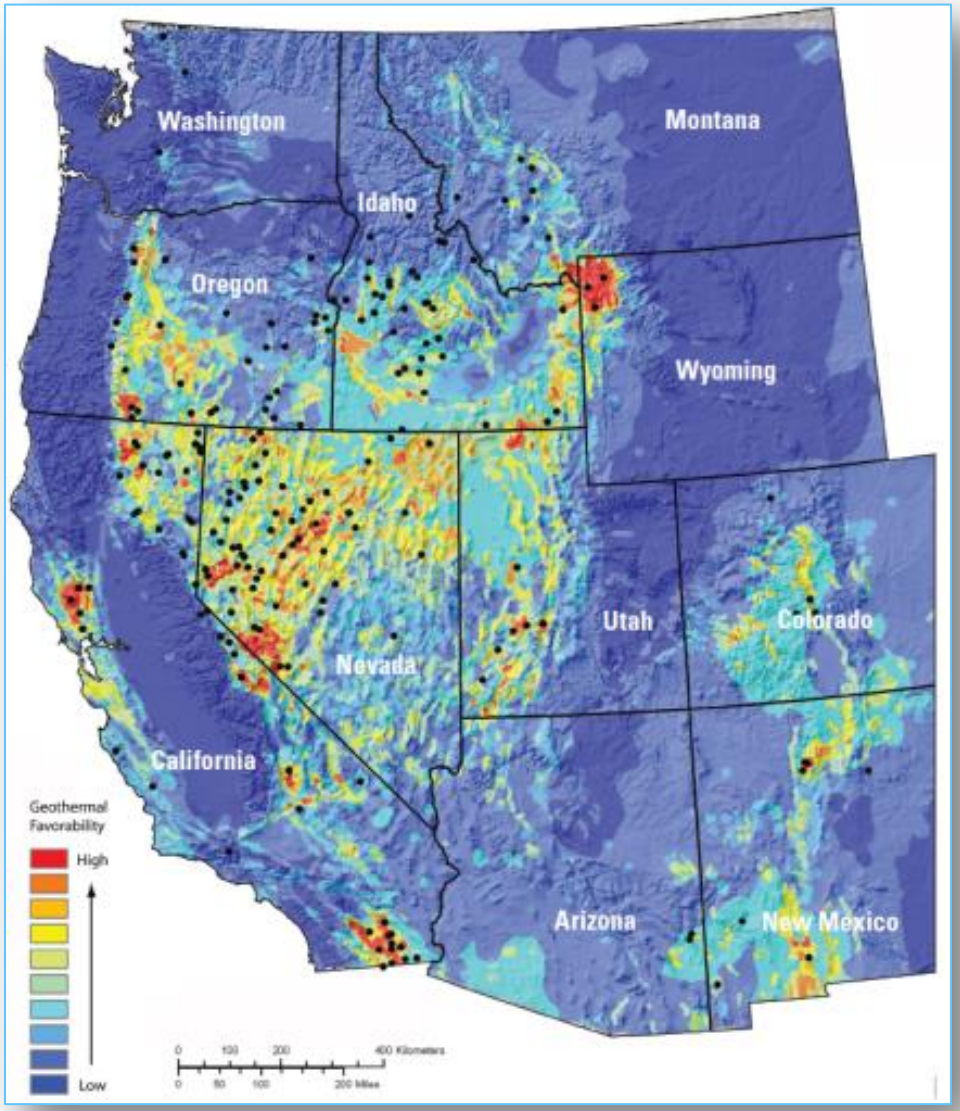
Expansion of Geothermal Resource Base

By USGS estimates, most of the hydrothermal resource in the U.S. is yet to be found.

USGS 2008 Hydrothermal Resource Potential

- Identified Hydrothermal sites: 9 GW
- Undiscovered Hydrothermal: 30 GW

→ Expansion of U.S. geothermal resource depends on discovery of new resources.



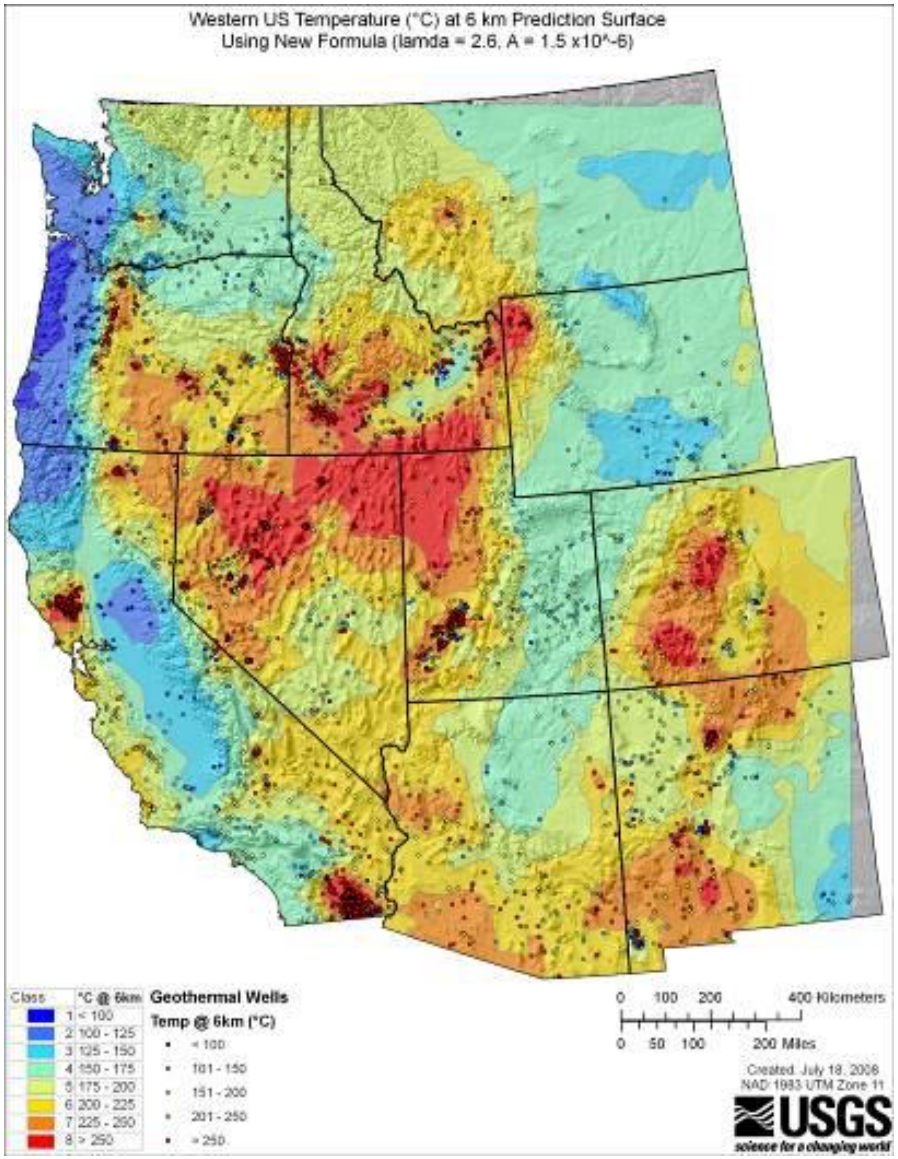
EGS Dramatically Expands Resource Base

Deep EGS Resource

- USGS 2008 Geothermal Resource Assessment
  - EGS potential in Western US
  - EGS potential for 3-6 km depth range
    - Excludes federally-protected lands (e.g. DOD, federal parks)
- Potential electric capacity calculation methodology:
  - Calculate heat in place for 1-km thick slices of rock
  - Apply recovery factor, heat recovery rate, and assumed plant efficiency for resource temperature
  - Multiply potential electric capacity of each resource temperature range by area covered on map

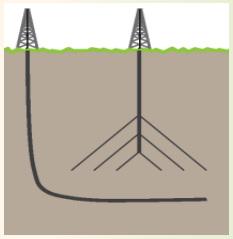
→ Over 500 GW_e potential

- Conservative estimate relative to MIT projection of 15,000+ GWe EGS potential for contiguous US at depths up to 10 km



Key Barriers to EGS Development

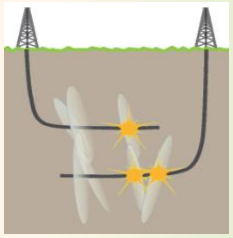
Technology Barriers	Field Testing at FORGE	GOAL



Reservoir Access
New well geometries and concepts, optimized drilling

Hard/Hot-rock drilling, completion technologies

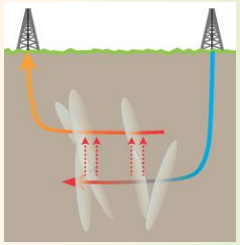
Rotary steering



Reservoir Engineering
Characterize local stress, zonal isolation, novel fracturing methods, increase fractured volume per well

Stress-field diagnostics

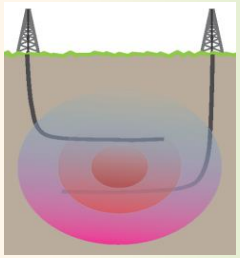
Smart tracers



Productivity
Increase flow rates without excessive pressure needs or flow localization

Zonal Isolation

High-T sensors



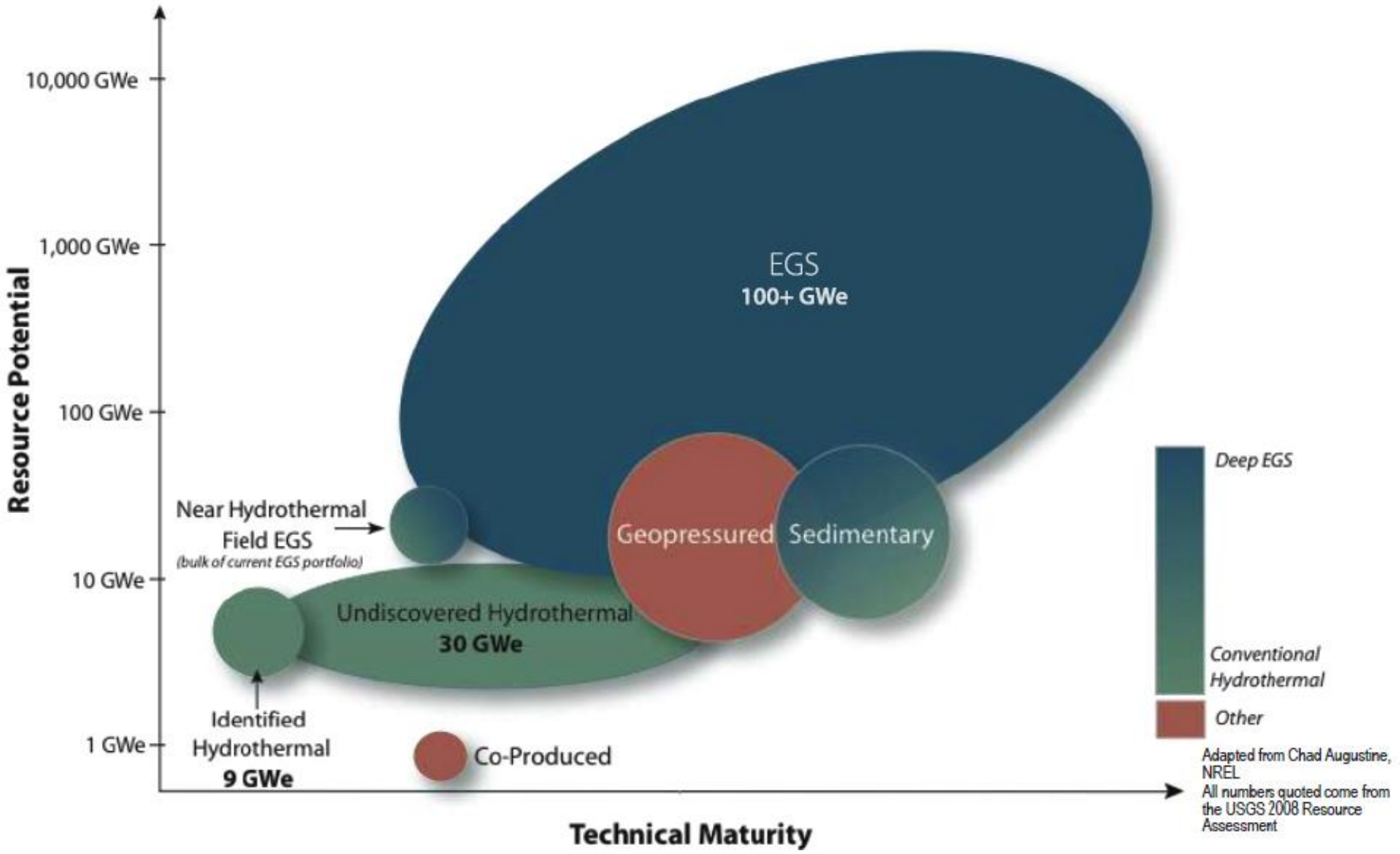
Sustainability
Maintain productivity with minimal thermal drawdown and water losses

Cross-well monitoring

Diverter technologies

EGS Success

Geothermal Resource Potential

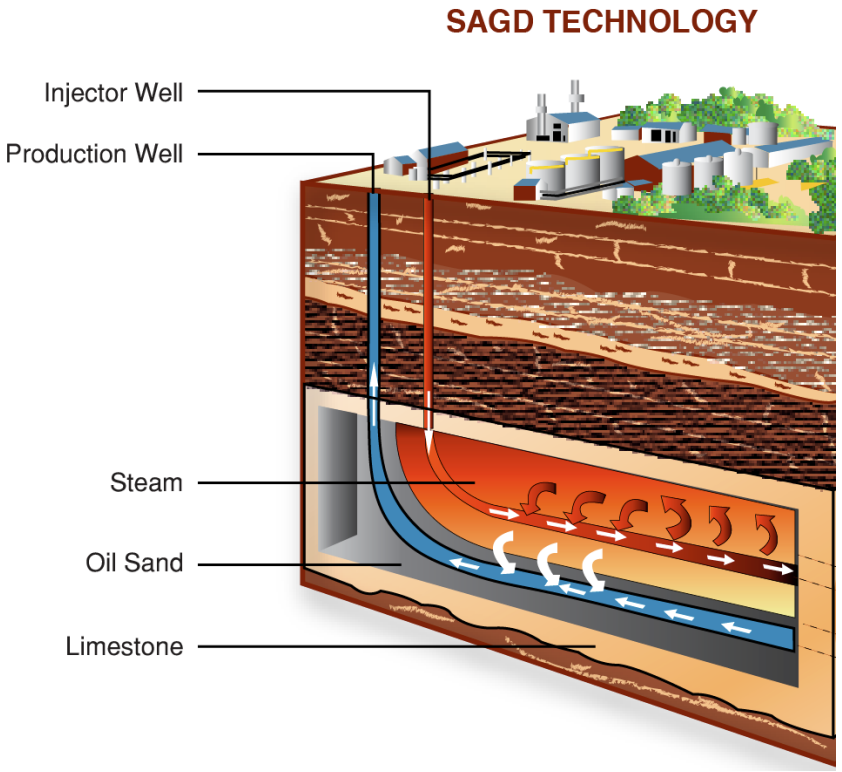


Source: Hollett (2012). "Stanford Geothermal Workshop Presentation," http://www1.eere.energy.gov/geothermal/pdfs/stanford_keynote_2012_hollett.pdf.

Innovation is Needed to Achieve Potential of EGS

Example innovations that might be adapted from the oil and gas sector

- **Steam Assisted Gravity Drainage (SAGD)**
  - Similar to EGS in reverse
    - Heat injected into resource
  - Similar temperatures
  - Similar components
- **High Pressure High Temp (HPHT)**
  - Extreme HPHT are ≥500ºF
  - Completion techniques are proven
    - Horizontal stimulation
  - Components commercially available
- **Unconventional Shale Plays**
  - Multi-stage fracturing



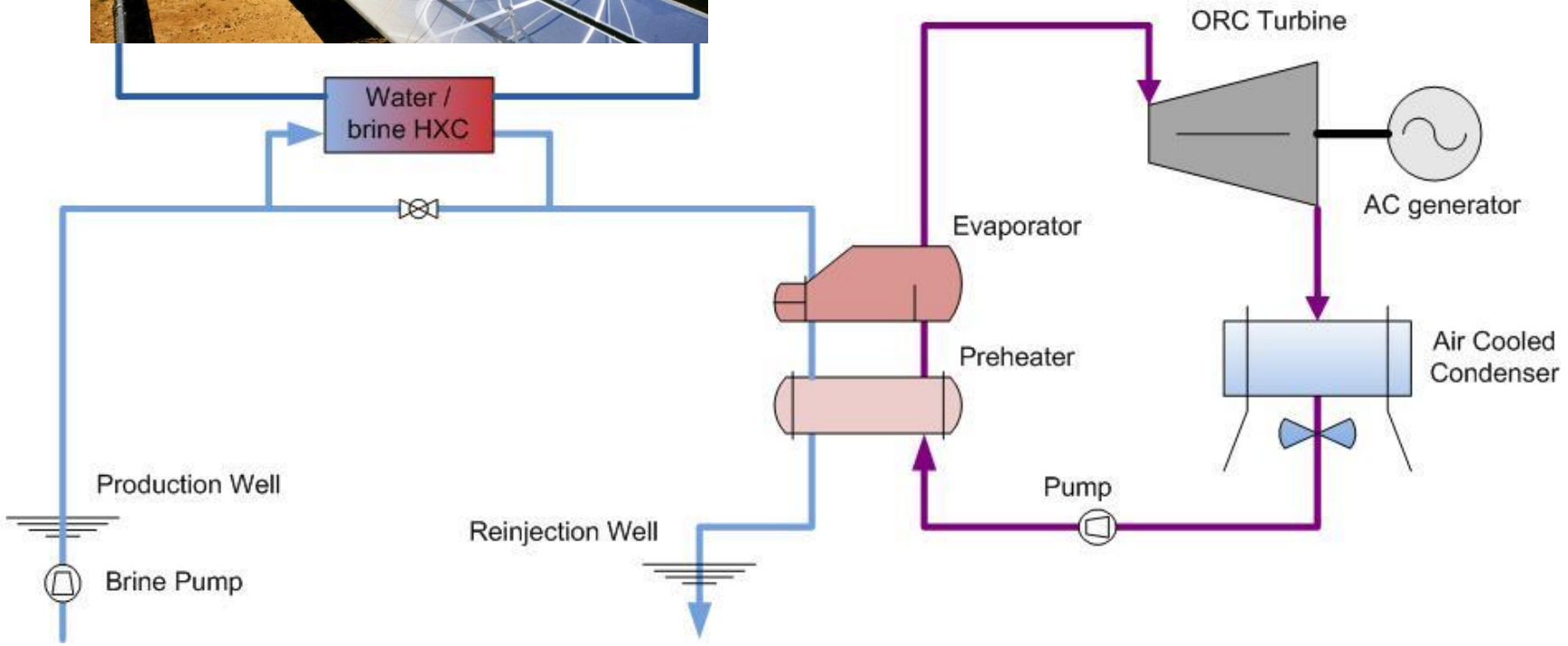
NREL NATIONAL RENEWABLE ENERGY LABORATORY

Colorado SURGE

COLORADOSCHOOLOFMINES EARTH • ENERGY • ENVIRONMENT

Other Innovations Can Create Opportunities

Example: Geothermal / Solar hybrid has high efficiency and increased output during summer peak load

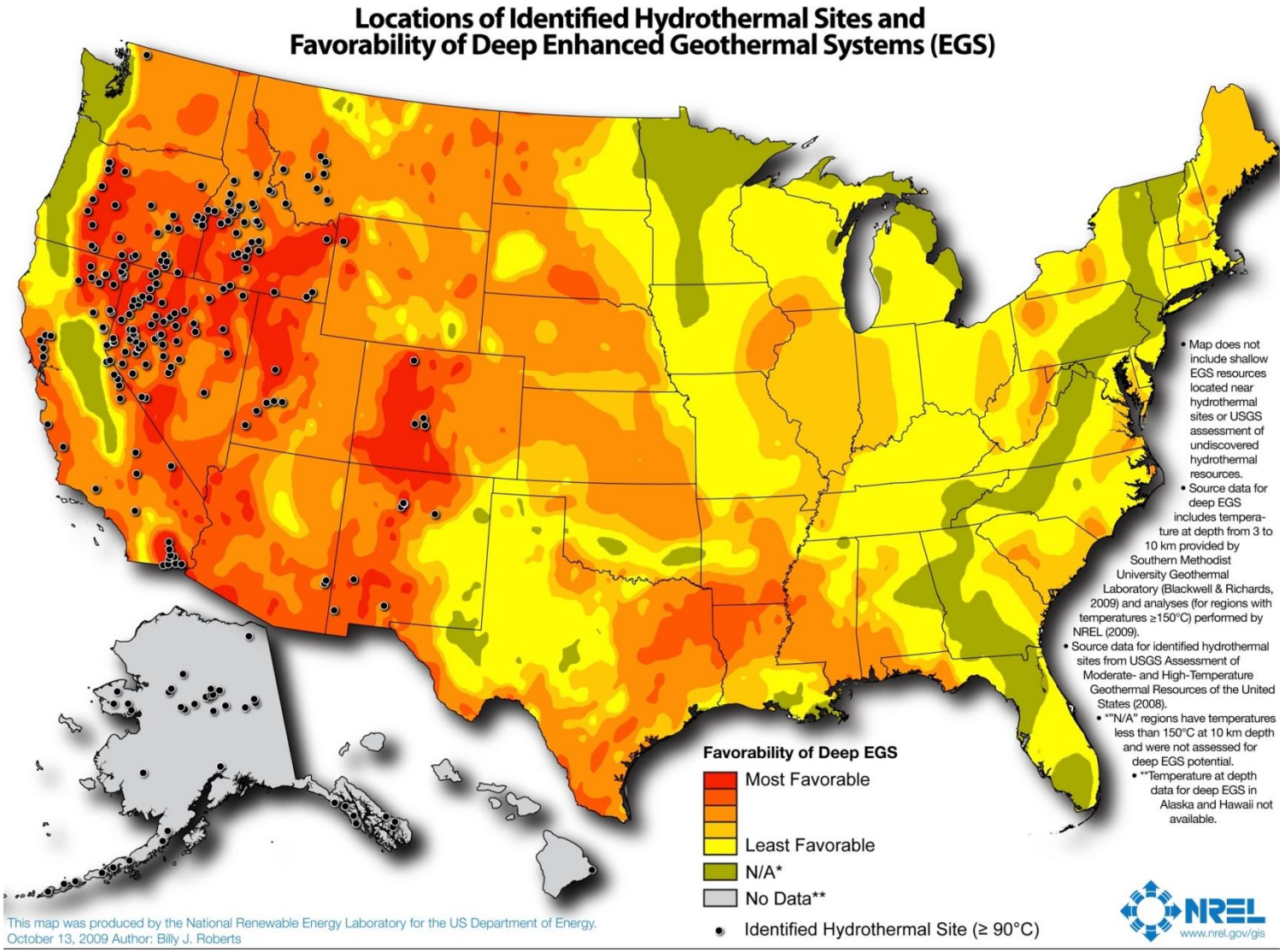


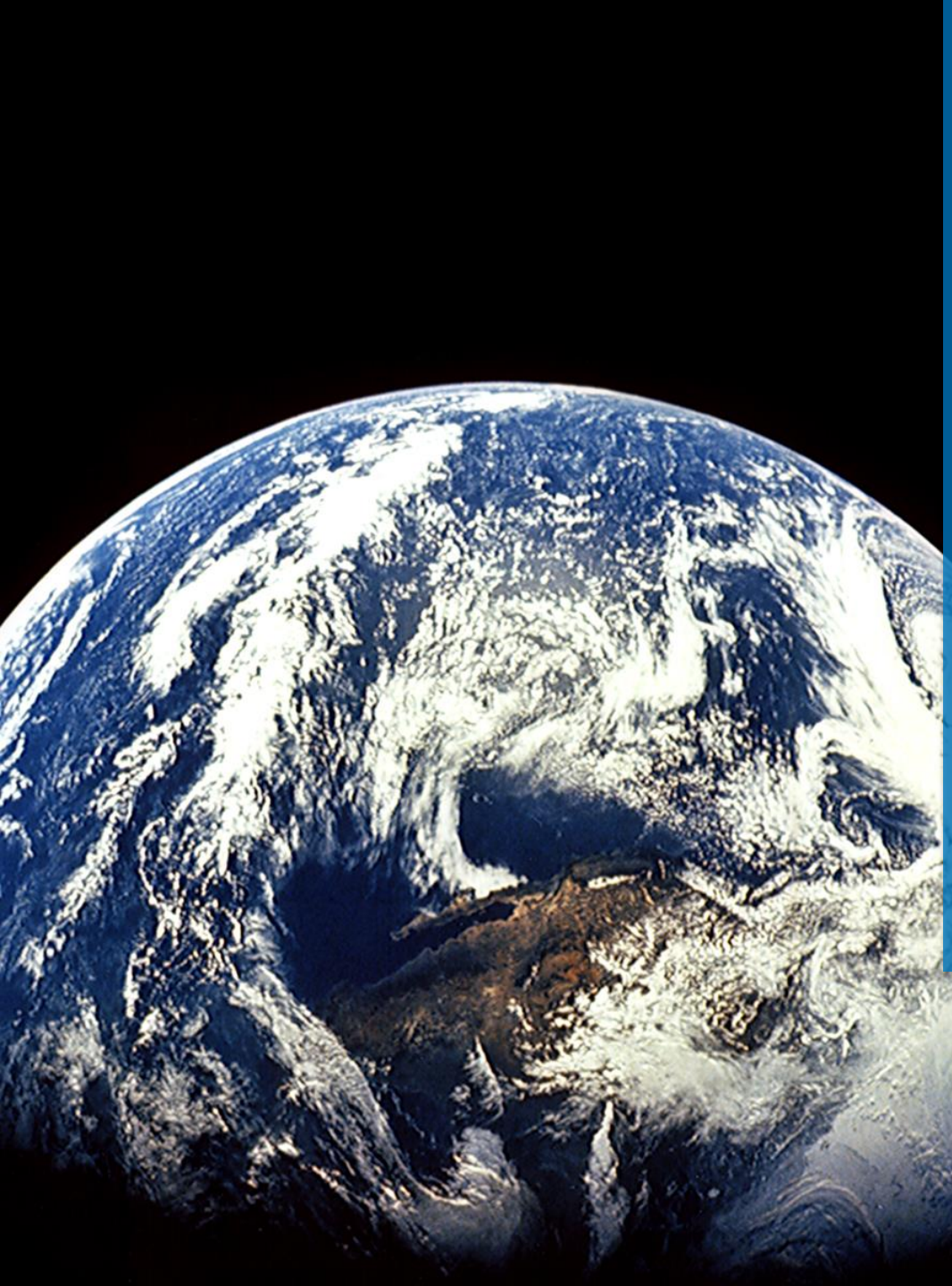
The Complementary Role of Geothermal, Wind, and Solar



- Shifting energy markets will create higher value for energy services, not just kWh
- Geothermal power has a unique set of strengths that support this challenge
  - Reliable availability of the resource 24/7
  - Spinning reserves
  - Direct thermal energy use options

U.S. Geothermal Resource Map





To achieve a high-impact geothermal vision, we must …

- **Understand the true potential of geothermal**
- **Invest in innovation**
- **Create effective partnerships**
- **Invent the future we desire**